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## Comparison of Techniques for Correction of Magnification of Pelvic X-rays for Hip Surgery Planning

Bertram The, M.D., Johan W. J. Kootstra, M.Sc., Anton H. Hosman, M.Sc., Nico Verdonchot, Ph.D.,  
Carina L. E. Gerritsma, M.D. Ph.D., and Ron L. Diercks, M.D. Ph.D.

The aim of this study was to develop an accurate method for correction of magnification of pelvic x-rays to enhance accuracy of hip surgery planning.

All investigated methods aim at estimating the anteroposterior location of the hip joint in supine position to correctly position a reference object for correction of magnification. An existing method—which is currently being used in clinical practice in our clinics—is based on estimating the position of the hip joint by palpation of the greater trochanter. It is only moderately accurate and difficult to execute reliably in clinical practice. To develop a new method, 99 patients who already had a hip implant in situ were included; this enabled determining the true location of the hip joint deducted from the magnification of the prosthesis. Physical examination was used to obtain predictor variables possibly associated with the height of the hip joint. This included a simple dynamic hip joint examination to estimate the position of the center of rotation. Prediction equations were then constructed using regression analysis. The performance of these prediction equations was compared with the performance of the existing protocol.

The mean absolute error in predicting the height of the hip joint center using the old method was 20 mm (range -79 mm to +46 mm). This was 11 mm for the new method (-32 mm to +39 mm). The prediction equation is: height (mm) =  $34 + 1/2$  abdominal circumference (cm).

The newly developed prediction equation is a superior method for predicting the height of the hip joint center for correction of magnification of pelvic x-rays. We recommend its implementation in the departments of radiology and orthopedic surgery.

**KEY WORDS:** Pelvic x-rays, hip joint, hip surgery planning

### INTRODUCTION

Total hip arthroplasty may be considered the most successful and frequently performed joint replacement in orthopedic surgery. Preoper-

ative planning on radiographs is widely accepted as the essential first step, and is performed to establish implant size and the technique to reconstruct leg length and the position of the center of rotation. Furthermore, it forces the surgeon to think 3-dimensionally, improves the precision of surgery, shortens the length of the procedure and greatly reduces the incidence of complications.<sup>1-6</sup> A prerequisite for accurate planning is accurate correction of the magnification factor of the x-ray on which preoperative planning is performed.

Although the need for accurate knowledge of the magnification factor seems obvious, available literature on the topic of determining the magnification factor for preoperative planning is limited. The first published study on this topic described a method (method A) to correct for magnification of pelvic x-rays by positioning an object of known dimensions—a calibration object—adjacent to the hip joint.<sup>7</sup> If the calibration object is positioned properly it can be used to correct for the magnification factor, thereby enabling accurate

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*From the Department of Orthopedic Surgery, University Medical Center Groningen, Hanzeplein 1, 9700 RB, Groningen, The Netherlands.*

*Correspondence to: Bertram The, M.D., Department of Orthopedic Surgery, University Medical Center Groningen, Hanzeplein 1, 9700 RB, Groningen, The Netherlands, Tel: +31-50-3610068; Fax: +31-50-3611737; email: b.the@orth.umcg.nl*

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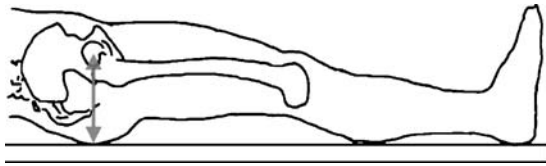


Fig 1. Height of the hip joint center. The patient is in a supine position on the x-ray table. The grey arrow indicates the height of the hip joint center. Calibration of the radiograph will be optimal if the calibration object is set at the same height as the hip joint center.

measurements or preoperative planning of hip surgery. More specifically, the center of the calibration object should be positioned at the same distance from the radiographic plate as the center of the hip joint. The distance from the table to the center of the femoral head will be referred to as the “height” of the hip joint center throughout this paper, assuming a patient in supine position on the examination table (Fig. 1). The Gorski paper describes in detail how to manufacture a device that can be used as a calibration object. However, no standardized method is described to position the calibration object correctly, although this is crucial in our opinion. Moreover, no experiment was performed to assess the validity and precision of its use in either laboratory circumstances or real practice. The second paper on this topic, by our own study group, described a method (method B), which was basically a refinement of method A.<sup>8</sup> Again, a reference object is used, which is positioned at the estimated height of the hip joint center. A standardized method to determine the location of the hip joint by palpation of the greater trochanter with the legs in maximal internal rotation was provided. However, a study in which method B had been employed failed to show more accurate prediction of hip prosthesis component sizes compared with using a standard magnification factor.<sup>9</sup> This might be at least partly caused by the errors in estimating the location of the hip joint center of method B. We have to conclude that, despite the urgent need for an accurate method to determine the height of the hip joint center for accurate positioning of calibration objects, no such method exists.

At least two other approaches, besides estimation by palpation of bony structures, seem feasible in clinical practice, but have not been investigated: the first option would be to use easily obtainable

patient variables (like hip circumference, body mass index, and sex) to predict the height of the hip joint center with the patient in supine position. The second option would be to use a dynamic hip joint examination (as is used in computer navigation-assisted surgery<sup>10</sup>) to localize the center of the hip joint by determining the center of rotation of the upper leg. Regression analysis could be used to identify which combination of variables is capable of providing us with an accurate estimate.

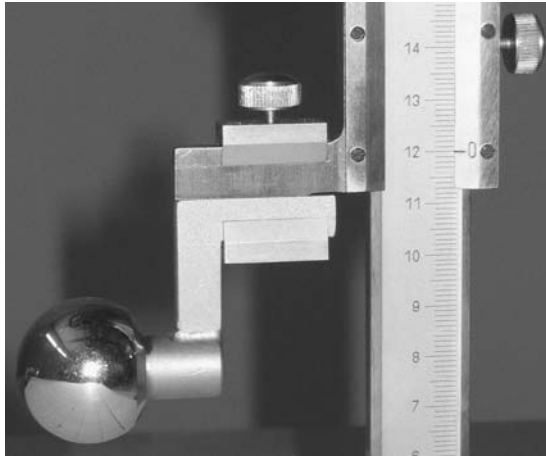
The first aim of this study was to determine the accuracy of method B. The second aim was to develop a method for more accurate prediction of the height of the hip joint center using easily obtainable patient variables or dynamic hip joint examination.

## MATERIALS AND METHODS

Institutional approval was obtained for the human protocol for this investigation. All investigations were conducted in conformity with ethical principles of research.

### Evaluation of Method B

From August 2001 to November 2004, 93 consecutive patients with one total hip replacement in situ, all with a 28-mm femoral head, were admitted to receive a total hip replacement on the other side. For the purpose of preoperative planning hip x-rays are not sufficient, so we chose to restrict ourselves to studying pelvic x-rays, which are the x-rays generally used in preoperative planning. The preoperative pelvic x-ray was made using method B; hence the patient was put in a supine position on the examination table. Both legs were maximally internally rotated, so that the greater trochanter was easy to palpate. The method assumes that, with internal rotation, the greater trochanter is approximately at the same level as the center of rotation. A marking was placed on the skin at the center of the area where the greater trochanter was palpable. The calibration device contained a prosthetic (28 mm diameter) femoral head (Fig. 2), which was set at the height of the skin marking. Next, a pelvic radiograph including the calibration object (which is positioned between the legs of the patient to ensure it is completely on film) is taken. The tube-



**Fig 2.** Calibration device. The 28-mm cobalt-chromium prosthetic femoral head can be adjusted in height. It is possible to adjust the settings on a millimeter scale using the integral ruler. It was manufactured to inform the user on the height of the center of the 28-mm sphere: when the femoral head was positioned as low as possible (thus the bottom side being in contact with the examination table), the indicator would point at 14 mm, as the center of the femoral head would indeed be halfway of the total diameter of the sphere.

to-table distance was standardized at 108.5 cm, whereas the tube-to-bucky distance was 115.0 cm. The radiograph was then digitized with a Howtek MultiRAD 760 scanner (AZTEK Inc., Irvine, CA) and was then calibrated by the computer using the projected diameter of the prosthetic femoral head and its known true diameter. This protocol of method B is described in detail in a paper published earlier.<sup>8</sup>

The reason for including only patients who already had a total hip prosthesis was that measuring the magnification of the prosthetic femoral head in situ was the only way to determine the true magnification of the hip joint. After calibrating the image using the calibration device, the diameter of the femoral head of the prosthesis in situ was measured (Fig. 3) using a standard measurement tool of the software package Ortho-CMS (Medis BV, Leiden, the Netherlands). The inter and intra-rater variance of these measures have been investigated in another study, and were 0.08 mm and 0.007 mm, respectively.<sup>8</sup> In the most desirable situation, the calibration object would be positioned at the same level of the prosthetic femoral head in situ. If that were indeed accomplished, measuring the diameter of the prosthetic head in situ would result in a value of 28 mm. Measuring a larger diameter of the

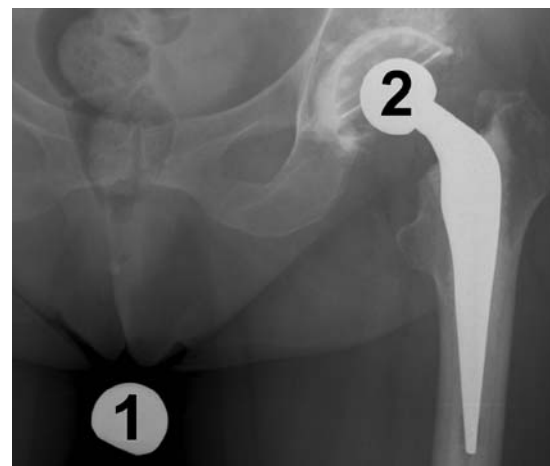
prosthetic femoral head would indicate that the calibration object had been positioned too low: the prosthetic femoral head in situ would then be more distant from the image plate than the calibration object, resulting in a larger projection of the femoral head in situ than the calibration object. A smaller diameter would indicate too high a placement of the calibration object.

## Development of a New Method

### *Predictors of Height of the Hip Joint Center*

From November 2004 to July 2005, 99 patients (mean age 70 years, 78% female) who came to the outpatient clinic for a routine control of a primary total hip arthroplasty gave informed consent to participate in this study.

During physical examination several variables of the patient were measured, which were considered to be possibly associated with the height of the hip joint center: height (cm), weight (kg), body mass index (BMI), hip circumference (cm), abdominal circumference (cm), hip width (cm), and antero-posterior depth at hip level (cm). Hip circumference and abdominal circumference were determined at the widest point with a flexible tapeline. Hip width was determined using a caliper whereby the distance between the two most lateral margins of



**Fig 3.** Evaluation of the current protocol. Calibration is performed on the calibration object<sup>1</sup>. Then the diameter of the implanted femoral head<sup>2</sup> is measured. The optimal result would be that the measurement is equal to the true diameter of the calibration object. If the calibration object is positioned too high, measurement of the diameter of the prosthetic femoral head will result in a value, which is too low, and vice versa.

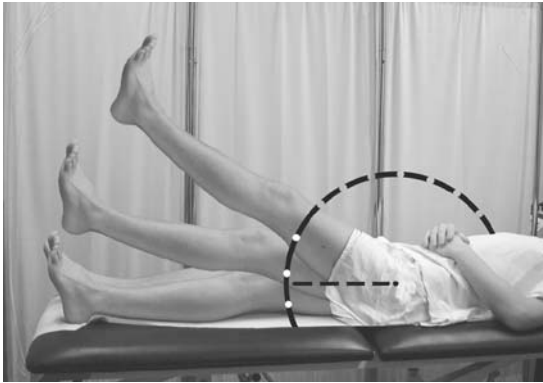


Fig 4. Dynamic hip joint examination. The patient was positioned in a supine position on an examination table and a marking was placed on the patient's leg (white dot). One of the investigators repeatedly anteflexed (up to 45°) and retroflexed (back to 0°) the patient's hip joint. The marking describes an arched path (circular line) during this procedure, with the center of rotation in its middle (black dot). A second investigator looked through a Perspex plate with a 1-cm horizontal and vertical scale, and marked the place on the plate where the marked point was the most distal during its path (horizontal line). The height (ie, the distance to the examination table) of this most lateral point theoretically corresponds with the height of the center of rotation of the hip joint. This estimated height of the center of rotation was noted as a candidate predictor of the height of the hip joint center, and should not be confused with the true height of the hip joint center (ie, the outcome variable), which was derived from the postoperative radiographs using exact mathematical solutions.

the patient's hip was measured at its widest point. Thus, no distinct bony landmarks were used for determining the superior-inferior level of measurement. This was arbitrarily judged to be the closest related to the height (distance from the table) at which the hip joint would be. In other words, it was deemed logical that the maximum volume of soft tissue near the hip joint was more important than the exact level at which the bulk of soft tissue was located. The size of the hip in anteroposterior direction was determined using a caliper whereby we measured the distance from the examination table to the anterior skin at the superior-inferior level of the pubic symphysis. This level of measurement was chosen to minimize the influence of soft tissue anteriorly of the hip joint. Lastly, a dynamic hip joint examination was performed to estimate the height of the hip joint center (Fig. 4).

#### *Measurement of Height of the Hip Joint Center*

First, the magnification factor of the hip joint is determined. The magnification factor would then

be transformed into our variable of interest: height of the hip joint center. The magnification factor itself is not a suitable outcome, since it is hospital-dependent: a patient will have radiographs with different magnification factors in different hospitals because the settings of the radiological equipment will be different. Using a film-focus distance of 100 cm and a table-film distance of 10 cm will yield radiographs with greater magnification than using a film-focus distance of 120 cm or a table-film distance of 6 cm (Fig. 5). A constant factor under all circumstances for the individual patient is the distance between the examination table and the center of the prosthetic femoral head: the height of the hip joint center. This distance corresponds with the height at which the calibration object should be set for the patient.

All patients had a pelvic radiograph made on the day they visited the outpatient clinic, when the predictor variables were measured. All patients had a total hip prosthesis in situ, and the magnification factor of the prosthetic head was digitally measured on this radiograph. As in the evaluation of method B, the reason for including only patients who already had a total hip prosthesis was that measuring the magnification of the prosthetic femoral head in situ was the only way to determine the true magnification of the hip joint. The radiographs were again digitized similarly to the radiographs used to evaluate method B.

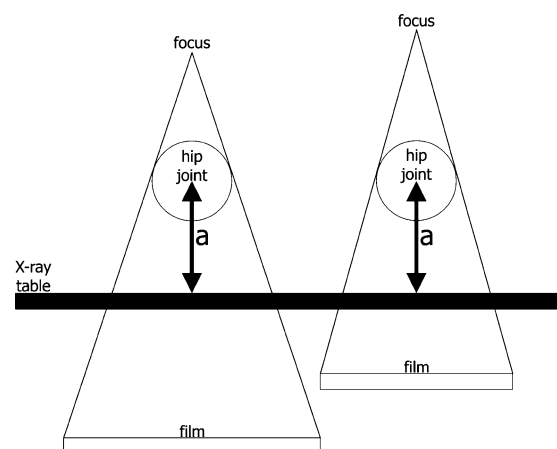


Fig 5. Variances in the magnification factor. Whereas the height of the hip joint center (distance a) is kept constant, the magnification factor will still vary with differences in film-focus distances or the distance between the x-ray table and the x-ray plate or film.

**Table 1. Patient Characteristics**

Variable	Mean	SD
Age (years)	70.1	9.8
Gender (% female)	78	
Length (cm)	166	8
Weight (kg)	78	13
Body Mass Index	28.2	4.5

SD = standard deviation

For the transformation of the magnification factor to the height of the hip joint center, an algorithm (which was validated in an earlier publication<sup>8</sup>) was used. For vertical displacement of a spherical object the following goes: [projected diameter] $=2 \times r \times h / \sqrt{y^2 - r^2}$ , where  $r$  is the radius of the sphere,  $h$  is the tube-to-bucky distance, and  $y$  is the distance from source to the center of the sphere. This algorithm needs the magnification factor and the film-focus and table-film distances—all of which were known—to calculate the exact height of the spherical object (in this case: the 28-mm prosthetic femoral head).

### Statistics

All variables were checked for normality using QQ plots (i.e., a quantile quantile plot, which is a scatterplot, with the quantiles of the scores on the horizontal axis and the expected normal scores on the vertical axis, used as a visual indicator of the distribution of the data) and histograms. Visualization of the shape of the relation between the separate variables and the outcome was done using multiple scatter plots. A univariate analysis was performed to identify the predictor variables that were significantly correlated with the magnification factor of the hip joint. All significantly correlated predictor variables were entered into a multivariate regression model. Subsequently, the least significant variables were deleted stepwise to obtain a prediction model with two predictor variables (the double predictor model) and a second model with only the strongest predictor variable (the single predictor model). Both predictor models were also used for individual predictions of the height of the hip joint centers. Cross-validation was done by performing bootstrapping. A comparison between the two new methods and method B was made by analyzing the errors of predicted heights of the centers of

rotation. All statistics were performed using SPSS 12.0 (SPSS Inc., Chicago) or S-Plus Professional 6.1 (Insightful Corporation, Seattle, WA).

### RESULTS

The baseline characteristics of the study population are summarized in Table 1. A total of five out of ten variables had a  $p$  value below 0.05 and were selected for use in linear regression analysis (Table 2). These were used for constructing the single and double predictor models. All percentages in the following section refer to the error in magnification factor, which are calculated as described in the Materials and Methods section. Using method B resulted in a range of errors from  $-79$  mm to  $+46$  mm (i.e.,  $-9.64\%$  to  $+6.43\%$ ) in estimating the height of the hip joint center, whereas this was reduced to a range of errors from  $-32$  mm to  $+34$  mm (i.e.,  $-3.13\%$  to  $+3.45\%$ ) using the double predictor model ( $H=10+\text{Hip Width}+1/3 \text{ Abdominal Circumference}$ ). The single predictor model ( $H=34+1/2 \text{ Abdominal Circumference}$ ) had a range of errors from  $-32$  mm to  $+39$  mm (i.e.,  $-3.69\%$  to  $4.13\%$ ). Mean absolute error in magnification was 20 mm (i.e., 2.39%) when using method B. This was reduced to 11 mm (1.08%) when using either the single or double predictor model (Table 3). It should be mentioned that the predictive power of the dynamic hip joint examination was less than

**Table 2. Selection Procedure of Predictor Variables**

	Correlation Coefficient	$p$ value
Hip width	0.329	0.001*
Abdominal circumference	0.352	0.001*
Weight	0.292	0.005*
Body Mass Index	0.287	0.006*
Hip circumference	0.235	0.025*
Dynamic estimate of CoR height	0.153	0.147
Anteroposterior measure at hip level	0.123	0.246
Gender	0.083	0.432
Length	0.041	0.698
Age	0.010	0.925

All correlation coefficients are Pearson Correlation Coefficients of the separate variables and the outcome variable Height of Hip Joint Center.

\* = Selected for the initial regression model. All  $p$  values are

**Table 3. Comparison of Methods to Determine Height of the Hip Joint Center**

	Prediction Equation	Range of Errors (mm)	Mean Absolute Error (mm)
Double predictor model	$H = 10 + HW + 1/3 AC$	-32 to +34	11
Single predictor model	$H = 34 + 1/2 AC$	-32 to +39	11
Method B	Estimate by palpation	-79 to +46	20

The double predictor model is the model that yields the most accurate estimates of the height of the hip joint center using two predictor variables, whereas, the simplest model yields the most accurate estimate using only one variable. These models are direct translations of regression equations, which assign the optimized weights for each covariate that has been entered in the model. Method B is the currently used method, which uses palpation of the greater trochanter to estimate the height of the hip joint center.  $H$  = distance in millimeters from the upper surface of the table to the center of rotation of the hip joint of the patient in supine position;  $HW$  = Hip Width in centimeters;  $AC$  = Abdominal Circumference in centimeters.

expected, which is the reason why it was deleted from the final predictor models.

### DISCUSSION

A new method to achieve accurate correction of magnification for pelvic x-rays was developed to enable accurate planning of hip surgery. The new method proved to be more accurate than the old method (method B) in estimating the height of the hip joint center to enable accurate calibration of pelvic x-rays.

This is the second study to validate a method for correction of magnification of pelvic x-rays. The first paper focused on the theoretical development of method B and used a small population for validation, which was only a secondary aim, whereas the results of using method B in another study were disappointing. Therefore, we deemed it necessary to duplicate the validation part of the first study with a larger population before continuing to develop a new method.

We have not attempted to develop a method that directly estimates the magnification factor. There are two clear advantages of using reference objects instead of direct estimates: first, the magnification factor is dependent on variables such as the distance between the x-ray table and the x-ray plate (which might differ between hospitals), whereas the height of the hip joint center is not. The second advantage is that variances induced by manual positioning of the x-ray source are eliminated by using a reference object, whereas the absolute magnification factor will be affected by it. Hence, if the calibration object is correctly positioned, correction of the magnification factor will be accurate with any

film-focus and table-film distances. Nonetheless, validation of the new method in other hospitals would still be valuable, especially if it concerns populations that differ in baseline characteristics from ours.

It is quite obvious that the height of the hip joint center is related to determinants associated with the geometry of the pelvis and fat distribution. The newly developed predictor models utilize the ability of these variables to predict the height of the hip joint center. Additionally, a dynamic hip joint examination was performed to estimate the location of the center of rotation of the hip joint. This was thought to provide us with a predictor variable, which is most directly linked to the location of the hip joint center. Unfortunately, this appeared not to be the case. This might be explained by the unreliability of the measurement method. To make the measurement suitable for use in clinical practice, we only used simple equipment (like a Perspex plate) and simple techniques (visual determination of the arched path, described by a marking on the skin). It seems that the trade-off between reliability and feasibility of the measurement method was not favorable in this study.

It is known that accuracy of preoperative plans for total hip arthroplasties is only moderate. Agreement between planning and actual intra-operative choice of component sizes is between 40% and 50%.<sup>11,12</sup> Digital preoperative plans were expected to perform better than conventional analog plans, but so far only small differences in accuracy were found. This is in contrast with planning of knee joint replacements in which digital planning is clearly superior to analog planning.<sup>9</sup> An important difference between the two joints is that it is easy to estimate the true

position of the knee joint (thereby enabling correct positioning of a calibration object), but it is difficult to estimate the true position of the hip joint.

The results of this study provide an accurate and easy to employ method to estimate the true position of the hip joint and to use it for more accurate correction for radiographic magnification of the hip joint. Although the double predictor equation was more accurate than the single predictor equation, the differences were only small. We, therefore, recommend implementation of the single predictor equation for accurate positioning of calibration objects and accurate correction of the magnification factor: height (mm)=34+1/2 abdominal circumference (cm). Future investigations are necessary to quantify how much improvement in accuracy of preoperative planning is actually achieved using this new technique.

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